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Testing QED by measuring a He* tune-out wavelength

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We report a new measurement for the 413 nm tune-out wavelength for metastable helium (He*); the optical wavelength at which the light does not interact with the atom, whose accurate determination provides a sensitive test of QED independent of transition energy measurements. Mitroy and Tang have shown[1] that the 413nm tune-out wavelength of the metastable 2^3S_1 state of helium is particularly sensitive to QED effects, and a measurement of this tune-out to 175MHz accuracy would constitute the most precise measurement of transition rate information made in Helium.

Comparison between the first theoretical estimate[1] and our first experimental measurement[2] was limited due to theoretical uncertainty. Recent calculations formulate the tune-out as a zero in the Rayleigh scattering cross-section for an atom interacting with an electromagnetic plane wave[3]. Accounting for perturbative QED corrections, the effect of finite nuclear size, and finite wavelength retardation corrections yields a predicted value of 725.744841(7) THz[4], compared to our first experimental value of 725.7393(16stat)(35syst) THz[2].

The key technical advance in our recent measurement is a pulsed atom laser technique which determines the in-trap oscillation frequency of a magnetically trapped Bose-Einstein condensate (BEC) to ten ppm in a single shot. Additional advantages are found in the increased probe beam power and frequency stability, and control of the polarization of the probe beam. The trap metrology technique enables differential measurements of the trap potential with 1pK (10^{-34}J) sensitivity, which we use to measure the shift in oscillation frequency as a function of the polarization and frequency of a focused probe beam.

Our experiment begins with a BEC of Helium in the $m_J = +1$ sublevel of the metastable 2^3S_1 state, confined in a cigar-shaped magnetic trap with harmonic frequencies $(\omega_r, \omega_z) \approx (550, 50)Hz$. After a magnetic impulse, we sample the centre-of-mass motion of the BEC with broadband radio pulses, transferring about 1% of the BEC to the field-insensitive $m_j = 0$ state, which freefalls for 416ms onto our delay-line detector. From the oscillation resolved on the detector we reconstruct the in-trap oscillation frequency by a non-baseband sensing method. We overlap the magnetic trap with an optical probe beam of fixed polarization and determine the wavelength at which the shift in BEC oscillation frequency vanishes - thus determining where the atom-light interaction is null at the tune-out wavelength.

We measure the tune-out wavelength for many different polarization states of the probe beam, from which we obtain a model to predict the tune-out wavelength for arbitrary polarization. We

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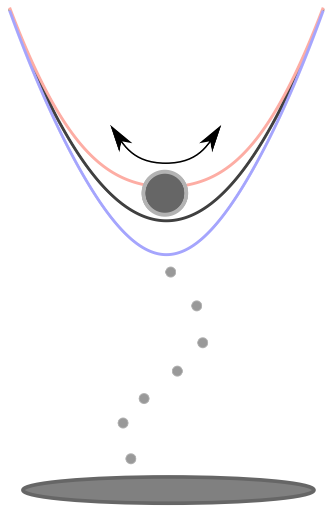

Figure 1: A BEC oscillates in a combined magnetic and optical trap. Broadband radio pulses transfer some atoms into untrapped states which freefall to the detector, where their position is resolved with $\sim 100 \mu m$ resolution. The oscillation frequency is obtained by fitting a damped sine wave and de-aliasing back to the appropriate frequency band, as determined by prior calibration. To first order, the trap spring constant shifts linearly with the detuning of the light from the tune-out frequency. Therefore, the tuneout frequency is that at which the trap frequency shift is zero.

identify the tune-out wavelength for a specified probe polarization, consistent with our previous measurement but this time accurate to (50stat)(150sys) MHz, a 25-fold improvement. We thus determine the value of the scalar polarizability minus half the reduced tensor polarizability, awaiting a detailed theoretical comparison.

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